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Syllables to Stress: A Cognitively Plausible

Technical Report AIP - 117

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This is the second of three papers from an ongoing research project on connectionist phonology. This paper shows how syllabification and a previously-described clustering mechanism can be used jointly to implement the stress assignment rules of a number of languages.

Earlier work in connectionist phonology is described in reports CMU-CS-89-144: "A Connectionist Implementation of Cognitive Phonology," CMU-CS-89-158: "Rules and Maps in Connectionist Symbol Processing," and CMU-CS-90-112: "Rules and Maps II: Recent Progress in Connectionist Symbol Processing."

From Syllables to Stress: A Cognitively Plausible Model

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Introduction

The underlying goal in our work is to develop a model of phonology which incorporates many of the insights of current phonological theories while at the same time being faithful to known constraints on processing in the human brain. If we can't possibly be going through long derivations when we are speaking, then what exactly are we modelling with our phonological analyses? One can draw a distinction between competence and performance here, but that is just begging the question. If we want to have a cognitively plausible model, we minimally need to constrain, if not eliminate, sequential and iterative application of rules, both of which result in long derivations with numerous intermediate stages. Quite simply, the problem is that there isn't time for the brain to perform long phonological derivations under normal circumstances.

In this paper we will address a range of issues pertaining to syllabification and stress. Our overall model is implemented in a connectionist framework, and this has imposed significant constraints on the nature of our phonological representations and rules (Touretzky and Wheeler 1990a). Our theory is constrained by two considerations. First, we want our descriptions to be implementable by simple circuitry. Second, our choice of circuitry (threshold logic units) is intended to capture, in a general way, the computational constraints of human brains. We will draw heavily on the work of Liberman and Prince (1977), Hayes (1981), Prince (1983), Hyman (1985), Halle and Vergnaud (1987), among many others, but none of these theories is directly compatible with the constraints of connectionist modelling. The theory of stress presented here requires no new/additional theoretical constructs, but simply draws on our independently-needed clustering operation for autosegmental processes like vowel harmony (Wheeler and Touretzky 1989). Using the clustering mechanism for stress as well as harmony may well be the first step in trying to understand the relationship between metrical and autosegmental theories of phonology.

Sequential and Iterative Application

Drawing on insights of Goldsmith (1990) and Lakoff (1989) we view the phonological component as consisting of three levels: M (morphophonemic), P (phonemic), and F (phonetic), with rules mapping between these levels. The labels are intended to be loose descriptive terms and do not necessarily correspond to the traditional usage of these terms. Lakoff recognizes two classes of rules: cross-level constructions (M-P and P-F) which state allowable correlations between levels, and intra-level rules (at P or F) which state well-formedness constraints within a level. Our theory is considerably more constrained than Lakoff's in that we do not allow rules to apply within levels, but only allow cross-level rules. This model offers the significant advantage that many sets of rules which had to apply sequentially in traditional analyses are now able to apply simultaneously.

Nasalization in French offers a fairly simple case to illustrate. The basic pattern is that vowels become nasalized before a nasal segment in the same syllable, then syllable-final nasals delete. In a standard analysis, this requires two extrinsically ordered rules (Schane 1968).

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(1) Vowel nasalization in French

Vowel nasalization: $V \rightarrow [+nasal] / __ [+nasal] \$$

Nasal deletion: $[+nasal] \rightarrow \emptyset / _\$$

- (2) /bɔn/ → bɔ̃n → [bɔ̃] 'good' (m.)
/bɔnte/ → bɔ̃nte → [bɔ̃te] 'goodness'

Obviously, nasal deletion must follow nasalization of the vowel, since the deletion process effectively destroys all environments where nasalization could apply. Even if it is possible to predict the ordering of these rules based on their (absolute bleeding) relationship, it remains the case that they must apply sequentially. When rules are viewed as mappings between levels this sequentiality is eliminated and both rules are free to apply simultaneously. If the environments for nasalization (3a) and nasal deletion (3b) are satisfied at P-level, then the changes are sanctioned at F-level, simultaneously, as shown in (3c).

(3a) Nasalization: P: V [+nasal] \$
 |
 F: [+nasal]

(3b) Nasal deletion: P: [+nasal] \$
 |
 F: Ø

(3c) M: $b \supset n$

P: b \supset n (vertical bars denote instances
 | | of rule application)
F: b \supset

Other instances of iterative/sequential rule application may similarly be eliminated on this view, where rules apply simultaneously wherever their structural description is met. Vowel shortening in Slovak is a good case to illustrate multiple, simultaneous application. As described in Kenstowicz and Kisseberth (1979:320), Slovak has a process which shortens vowels after long vowels. In a sequence of long vowels, all but the first shorten. The desired effects follow straightforwardly if shortening is stated as a cross-level rule, as noted by Lakoff (1989).

(4a) Slovak Shortening Rule

P: V: V:
F: [-long]

(4b) Schematic Example

$$\begin{array}{ccccc} \mathbf{P:} & \mathbf{V:} & \mathbf{V:} & \mathbf{V:} & \mathbf{V:} \\ & & | & | & | \\ \mathbf{F:} & \mathbf{V:} & \mathbf{V} & \mathbf{V} & \mathbf{V} \end{array}$$

Here again, we get all the right predictions by simply viewing rules as altering the mapping between levels within the phonological component. Where simultaneous application of rules will not work is in iterative cases where the application of a rule creates the environment for the rule to reapply. In the following section we will describe the mechanism for accounting for these processes and offer a general description to the typology of rule types in this model.

The Clusterer

Autosegmental phonology (Goldsmith 1976) offers a very nice account of phonological processes apparently involving the iterative spreading of some feature or features over extended domains. We will use Yawelmani vowel harmony to illustrate. As is well known, the basic pattern in Yawelmani is that vowels become round and back when following a round vowel of the same height. In a standard generative account, this rule would be formalized as in (5) below. Derivations like the one in (6) clearly show that the rule applies iteratively, left to right. Harmony must apply after epenthesis since the epenthetic vowel undergoes harmony. Furthermore, iterative application of the rule is required since rounding of the epenthetic vowel subsequently triggers rounding of the following vowel. This is just exactly the mode of rule application which needs to be avoided if we are to strive for a plausible characterization of our phonological competence.

(5) [+syll, α high] \rightarrow [+round, +back] / [+syll, +round, α high] C₀ ____

(6)	/ ? u g n + h i n /	'drinks'
	i	epenthesis
	u	harmony on the epenthetic vowel
	u	harmony on the final vowel
	[? u g u n h u n]	

In an autosegmental analysis the feature [round] would be represented on a separate tier and would spread, left to right, to all vowels which agree in height. In principle, the theory leaves open the question of whether the association of autosegments is sequential or simultaneous, though most descriptions of autosegmental association imply sequentiality. Wheeler and Touretzky (1989) proposed to account for such processes through the use of a clustering mechanism. Clusters are formed by specifying trigger and element segments. Iterative application of rules is avoided by first clustering elements in a string and then simultaneously making the change in all segments marked as elements. Our cluster rule for Yawelmani vowel harmony is given in (7). The construction of clusters is described in (8): universal restrictions are stated in (8a) and the algorithm in (8b).

(7) Yawelmani Vowel Harmony

Cluster type	[+syllabic]
Direction	L-to-R
Trigger	[+round, α high]
Element	[α high]
Domain	unbounded
Change	[+round]

(8a) Segments can't be both triggers and elements.
Segments prefer to be elements.
Elements must be adjacent to triggers or other elements.

(8b) Turn on trigger and element bits for all segments meeting the specifications.
Next, turn off element bits with no trigger or element bit on to their left
(or to the right in R to L cluster).
Finally, turn off any trigger bit whose corresponding element bit is on.

(9a)	/ u i i /	(9b)	/ u i i a i /
trigger	+	trigger	+
element	++	element	++
	[u u u]		[u u u a i]

$$(10) \quad V: V: V: V: \rightarrow V: V \quad V: V$$

(11a) V: → [-long] / V: _____

(11b) /V: V: V: V:/
 V
 V
 [V: V V: V]
 first application of shortening rule
 second application of shortening rule

(12a) **Gidabal shortening**

Cluster type	[+syllabic]
Direction	L to R
Trigger	[+long]
Element	[+long]
Domain	bounded
Change	[-long]

	V:	V:	V:	V:
trigger	+		+	
element		+		+

Vowel shortening applies to all elements in the domain, resulting in the desired alternating pattern. It is the boundedness of the domain, forcing elements to be adjacent to triggers, that causes the alternating pattern of shortening.

The previous discussion has illustrated three of the four major types of rules allowed in our model. The overall typology is given in (13). There are segmental operations and clustering operations; with the term 'segmental operation' being used to refer to all the cross-level mapping rules which have a local context and do not rely on the clusterer. Each class of rules is further sub-divided on the basis of whether or not adjacent segments play a role in the specification of the rule. Default rules, as in the case of Yawelmani where all [+round] vowels are [+back], fall into the class of non-restricted segmental operations.

(13)	restricted	non-restricted
cluster operations	bounded clusters (Gidabal shortening)	unbounded clusters (Yawelmani harmony)
segmental operations	context sensitive (French nasalization) (Slovak shortening)	context free (Default rules)

The discussion to this point has focussed on the nature of rules and their mode of application. In the proposed model, all rules apply simultaneously, in parallel across the entire domain. Apparent cases involving iteration are accounted for by means of the clustering mechanism which identifies elements to undergo the rule. Another area in which iterative application of rules is typically necessary is in stress rules. Whether one assumes a metrical or a segmental account of stress it is necessary to apply the rules iteratively in order to account for alternating patterns. Before showing how iterative application of stress rules can be eliminated in the same fashion as with segmental processes discussed above, it is necessary to digress briefly and consider the internal structure of syllables.

Syllabification

We assume here, following Itô (1986), that syllabification is governed by the principle of Prosodic Licensing, which states that all phonological units must be prosodically licensed, that is, belong to higher prosodic structure. Thus, all segments must be syllabified in order to be realized phonetically. Prosodic licensing forces exhaustive syllabification, and any unlicensed segments are effectively deleted (cf. Stray Erasure, McCarthy 1979). We assume that syllabification is subject to universal as well as language-specific well-formedness conditions.

Syllable weight, commonly characterized in terms of 'branching structures' in metrical analyses (Hayes 1981) plays an important role in determining the stress pattern of many languages. Consistent with the framework we are assuming, we encode the prosodic category in additional bits associated with each segment (see Touretzky and Wheeler 1990b for further discussion) rather than trying to explicitly encode tree-like structures. On this view, syllabification of phonological strings uses the same general mechanisms utilized above, with the position of the segment within a syllable being encoded directly through the specification of whether the

onset, nucleus, or coda bits are active. As an example, consider the syllabification of a word like 'picnic' in English, which, in our model, would be represented as:

- (14)
- | | | | | | | |
|---------|---|---|---|---|---|---|
| | p | l | k | n | l | k |
| onset | + | | | + | | |
| nucleus | | + | | | + | |
| coda | | | + | | | + |

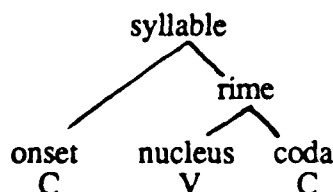
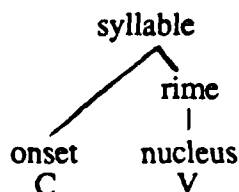
This is obviously a more restrictive theory since there are no hierarchical structures which can be referred to or manipulated by rules of the phonology. In essence, one is limited to statements about the category of elements in the string; the class of rules is similarly restricted. The basic syllabification algorithm is given below. Syllabification is governed by the universal constraints in (15a). We assume here that the syllabification process (15b) is subject to constraints imposed by the sonority hierarchy and/or language-specific prosodic licensing.

- (15a) [+syllabic] segments are part of the nucleus.
 [-syllabic] segments prefer to be onsets rather than codas.
 Onsets must have a nucleus or another onset segment following.
 Codas must have a nucleus or another coda preceding.
 Segments can't be both onsets and codas.
- (15b) Turn on the nucleus bit for [+syllabic] segments.
 Next, turn on the onset bit for [-syllabic] segments to the left of the nucleus.
 Then, turn on the coda bit for [-syllabic] segments to the right of the nucleus.

In English, the intervocalic /kn/ sequence is not a possible onset cluster, so only the /n/ may be marked as an onset. This initial parsing of the string into onset, nucleus and coda provides the basis for weight distinctions between syllable types.

In standard metrical analyses of stress, following Halle and Vergnaud (1978) and Hayes (1981), it was originally assumed that the geometry of phonological representations plays an important role in characterizing syllable weight. The stress patterns of languages commonly distinguish between heavy and light syllables, with heavy syllables attracting stress. In metrical theory, heavy syllables have branching rimes, as illustrated schematically below.

- (16) Light/open syllable: Heavy/closed syllable:



The stress rules may theoretically be sensitive to this branching structure, and in quantity-sensitive languages it is assumed that there are restrictions on the distribution of syllables with branching rimes in the higher, foot-level structures (Hayes 1981, Hammond 1986, among others). This is a clear case where the choice of framework radically constrains the nature of representations. The

geometric notion of a branching rime, while appealing in its own right, has no conceivable meaning in the framework adopted here.

In our model, weight relations are encoded in the same way as the internal constituents of the syllable. That is, through the simple mechanism of activating bits associated with each segment. Here again, there is an interaction between universal and language-specific constraints. We draw on the insights of moraic phonology and define heavy syllables as syllables consisting of two moras (Hyman 1985). We will illustrate with a hypothetical example from a quantity-sensitive language in which both syllables with long vowels and closed syllables are treated as heavy. Suppose the output of the syllabifier is as shown in (17), where language-specific constraints on prosodic licensing do not allow the medial tri-consonantal cluster to be an onset.

(17)		#	C	V	C	V	C	C	C	V	V	#
	onset		+		+			+	+			
	nucleus			+		+				+	+	
	coda						+					

If, as hypothetically assumed in this example, long vowels and syllable-final consonants contribute to 'weight', this will be encoded by activating the mora bit for these segments. What may contribute to the weight of a syllable is clearly a language-specific parameter. Once moras have been identified, universal principles come into play, and bits for syllables and heavy syllables are activated. The syllable bit is activated for the first of a string of moras; the heavy syllable bit is activated whenever there are two adjacent moras. These simple steps allow for the encoding of the weight relations which play a role in the prosodic systems of languages. The stress rules of quantity-insensitive languages will target the 'syllable tier', while quantity-sensitive languages will target the 'heavy syllable tier'.

(18)		#	C	V	C	V	C	C	C	V	V	#
	onset		+		+			+	+			
	nucleus			+		+				+	+	
	coda						+					
			<hr/>									
	mora			+		+	+			+	+	
	syllable			+		+				+		
	heavy syllable					+				+		

The term 'heavy syllable' is being used here to encode various types of weight relations. While the case described above is the most common, there are other possible ways to define what counts as a heavy syllable. If long vowels but not closed syllables count as heavy, then only [+syllabic] elements will be moraic, and consequently syllables with long vowels will be the only ones to show activation of the 'heavy syllable' bit:

(19)		#	C	V	C	V	C	C	C	V	V	#
	mora			+		+				+	+	
	syllable			+		+				+		
	heavy syllable									+		

Furthermore, and we see this as a strong advantage to this approach, our model is flexible enough to account for the so-called onset-sensitive languages discussed in Everett and Everett (1984) and Davis (1985). These languages are an embarrassment for standard approaches which characterize weight in terms of the geometric property of branching rimes. On a language-specific basis, it is possible to specify that the onset of a syllable should be moraic. In that case, the 'heavy-syllable' bit would still be activated when there are adjacent mora bits. The marked status of these patterns would seem to relate to the added stipulation that the 'second' of the two adjacent moras actually precedes the nucleus. Since there is no explicit representation of the hierarchical structure within a syllable in terms of a tree structure we are better able to account for the range of weight relations found in languages. The important thing to notice here is that it is possible to encode all the relevant weight distinctions without having to impose any explicit constituent structure on the phonological string.

Stress

A great deal of attention has been paid to the stress patterns of languages since Liberman and Prince's (1977) article on metrical theory. Various theories have developed, each emphasizing different aspects of the representation and the relation between trees/constituency and grids (Prince 1983, Hammond 1986, Halle and Vergnaud 1987). Building on Hayes (1981), a theory of parameters in stress rules has developed, and the notions of boundedness, headedness and directionality are common to all current metrical theories. In this section, we will argue that these properties of stress rules actually follow from more general properties of the model we are developing and that stress rules fall very naturally into the rule typology discussed earlier. Furthermore, we will show that the effects of tier conflation and heavy syllable accent (Halle and Vergnaud 1987) follow without having to be independently stipulated.

The two major classes of rules are: cluster rules and segmental operations. Within each set, there are rules with a restricted context and rules which are not sensitive to the broader context of the segment. The class of possible stress rules fits very naturally into this classification, filling at least three of the four predicted rule types. We will return to the question of the one case which is apparently missing (a non-restricted cluster rule) after illustrating the other patterns.

(20)	restricted	non-restricted
cluster operations	bounded clusters (alternating patterns)	unbounded clusters (*stress clash)
segmental operations	context sensitive (first/last, second/penult)	context free (all heavy)

First, consider the class of rules we are characterizing as non-restricted segmental operations. Stress rules of this type will assign stress to all heavy syllables, or perhaps to all long vowels if only [+syllabic] segments are moraic. For example, consider a language like that represented in (18) above, where all closed syllables and syllables with long vowels count as heavy. If all heavy syllables bear stress, the rule would be simply:

- (21) M [heavy-syllable]: []
 |
 P: [+stress]

This rule is to be interpreted as saying that any segment in the heavy-syllable projection of the M-level should be stressed at P-level. Stress will be assigned to all segments in the heavy-syllable projection since there are no additional restrictions on the rule. Adding a context to the rule, or restricting its application, offers an example of the other class of segmental operations. Incorporating a word boundary into the rule describes patterns where the first/last constituent on a particular tier bears stress. Stressing only the first heavy syllable of a word requires only a minor modification of the above rule, yielding (22). The mirror image of this rule would stress the last heavy syllable of a word. Again, the rule operates on the heavy-syllable projection.

- (22) M [heavy-syllable]: # []
 |
 P: [+stress]

In Halle and Vergnaud (1987) a simple stress pattern like this would require a fairly complicated analysis, forced by the assumption that words must be exhaustively constituentized. In this case, unbounded, quantity sensitive constituents would have to be constructed for the entire word. Tier conflation would then have to apply in order to eliminate any secondary stresses which would otherwise be predicted to appear. None of the complexity of this sort of derivation is necessary in the proposed analysis.

The rule must be slightly more complicated in order to account for stress falling regularly on the second or penultimate syllable of a word. The following rule, operating on the syllable projection, accounts for stress on the second syllable, and the mirror image would predict stress consistently on the penultimate syllable.

- (23) M [syllable]: # [] []
 |
 P: [+stress]

Again, this analysis is considerably simpler than what would be required in Halle and Vergnaud's theory where bounded constituents must be constructed over the entire domain; with tier conflation being invoked to suppress the stresses predicted to occur on all constituents other than the peripheral one.

Alternating stress patterns are accounted for by the other major subset of rules: cluster rules. Drawing on the discussion of clustering operations earlier, recall that these rules have the following parameters. For stress rules, the options are as specified.

- (24) Cluster type mora, syllable
 Direction (R-to-L) or (L-to-R)
 Trigger same as cluster type
 Element same as cluster type
 Domain bounded
 Change [+stress]

Consider a language like Southern Paiute in which stress falls regularly on all even moras of the word. This can be accounted for by a rule which operates from left to right on the mora tier, forming bounded clusters. In a left to right clustering operation, specifying that the domain is bounded means that an element must be immediately preceded by a trigger. Even though there is a general preference for segments to be elements rather than triggers, in the following case the third syllable, for example, cannot be an element since it is not preceded by a segment with the trigger bit activated. Therefore, it is free to act as a trigger. As with all previously described cluster rules, the specified change affects all elements in the domain simultaneously.

(25)

	#	C	V	C	V	C	V	C	V	C	V	C	V
mora			+		+		+		+		+		+
syllable			+		+		+		+		+		+
heavy syllable													
trigger			+			+			+			+	
element				+			+			+			+
change				[+stress]			[+stress]			[+stress]			[+stress]

Another common type of alternating pattern is one in which all odd numbered syllables are stressed, as in Maranungku. Here again, clustering would operate on the syllable tier, forming bounded clusters. In order to have a basic trochaic (S-W) pattern we need only assume that, on a language-specific basis, the boundary may act as a trigger. This offsets the alternating pattern by one and allows the initial syllable to be an element, and hence stressed. Nothing per se hinges on the 'existence' of # as a symbol in the representation. Whatever serves to demarcate word boundaries could be marked as the trigger.

(26)

	#	C	V	C	V	C	V	C	V	C	V	C	V
mora			+		+		+		+		+		+
syllable			+		+		+		+		+		+
heavy syllable													
trigger	+			+			+			+			+
element		+			+			+			+		
change		[+stress]			[+stress]			[+stress]			[+stress]		

Parallel accounts can be given for alternating patterns reckoned from the end of the word. The only difference would be in the specification of the direction parameter. Similarly, alternating stress patterns which count moras rather than syllables would simply define clusters on the moraic tier rather than the syllable tier.

Our rule typology predicts one remaining subclass of stress rules, which apparently do not exist. Namely, given the range of possible segmental rules, we would expect to find something parallel to the unbounded clusters of harmony processes in stress rules. We know of no such rules, and therefore restrict the 'domain' parameter above to only bounded clusters. Before giving a possible explanation for this gap, consider what the theory predicts should be possible, in principle. Suppose we were to form unbounded clusters on the syllable tier from left to right. Since all elements in a cluster are stressed, we would derive the following pattern, where all but the first syllable is stressed:

(27)

	#	C	V	C	V	C	V	C	V	C	V	C	V
mora			+		+		+		+		+		+
syllable			+		+		+		+		+		+
heavy syllable													
<hr/>													
trigger element			+				+				+		
change							[+str.]				[+str.]		

Our position at this point is to attribute this gap in the predicted patterns to a more general tendency in languages to avoid adjacent stressed elements. We can account for the lack of such rules by restricting clustering operations for stress rules to bounded domains. Thus, if the feature specified in the rule for the 'change' were, say, [+round], as in Yawelmani, everything would be fine. As a consequence, it is now clear how our model offers a unified interpretation of metrical and autosegmental phenomena. The clusterer is playing a crucial role in all non-local operations of this sort; only the nature of the change specified in the rule differs.

Secondary Stress: The Interaction of Rules

Up to this point we have considered assignment of stress, but have not made any distinction in the relative prominence of the stressed syllables of a word. The general pattern which emerges, on this view of stress rules, is that the distinction between primary and secondary stresses is derived by superimposing the effects of a clustering rule and a segmental operation, with main stress falling on the vowel at the intersection of the two rules. Thus, consider a language like Maranungku (Tryon 1970), which is reported to have main stress on the initial syllable and secondary stresses on every other syllable to the right of the main stress. This pattern is derived straightforwardly by assuming that there is a cluster rule for stressing all odd numbered syllables from left to right, together with a segmental operation that stresses the initial syllable.

The significant advantage to adopting this approach is that we predict that there should be three classes of languages, without having to extend the theory by incorporating any additional theoretical constructs like tier conflation. We expect to find languages like Tübatulabal (Voegelin 1935) which have alternating patterns where all stressed syllables are of equal strength, as well as languages like Finnish which show only a single stress on the initial syllable, as well as the more complicated cases like Maranungku, where there is an interaction of a clustering rule and a segmental operation. A further consequence is that for large classes of languages, the number of distinct stages in derivations is significantly reduced and thus the processing time for the application of rules is reduced. This brings us back to the original motivation for seeking an alternative to standard generative analyses: the desire to eliminate iterative application of rules and sequential derivations.

As an example of how our proposed theory significantly reduces the complexity of derivations, consider the stress pattern in Aklan, a Philippine language spoken on the island of Panay. According to Halle and Vergnaud's description, citing Chai (1971) and Hayes (1981), stress falls on all closed syllables, on certain lexically marked syllables, and in a sequence of open syllables on every odd syllable counted from the right if the sequence is word-final and on every even syllable if the sequence is not word-final.

-12-

metathesizes an asterisk and its boundary on line 1, yielding the following derivation:

(33a) Metathesis rule (Halle and Vergnaud 1987:46)

$$\begin{array}{ccccccc} * &) & \rightarrow &) & * & / & * & \text{---} & \text{line 1} & \text{word finally} \\ & & & & & & * & * & \text{line 0} \end{array}$$

(33b)

				*	line 2				*	line 2	
(*		*	*	line 1	→	(*		*	line 1
(5	4)	(3	2)	(1)	line 0		(5	4)	(3	2)	(1)
											line 0

Having to resort to a metathesis rule is clearly unfortunate and preferably should be avoided. Not only does it introduce an extra stage in the derivation, necessarily applying after the regular rules constituentizing the string, but it also leads to a less restricted theory in that the constituent boundary and asterisk are treated as independent entities which can be manipulated. There is no doubt that this is a relatively complicated pattern, but we will now turn to an alternative analysis which makes it far less so.

The surprising thing about Akkan is that the stress pattern seems to be incorporating rules from each of the three different possible types of stress rules. Assuming that syllabification and weight assignment have taken place, all closed syllables will be marked on the heavy syllable tier. An MP rule of the following form will account for what Halle and Vergnaud refer to as 'heavy syllable accent'.

(34) M [heavy-syllable]: []
 |
 P: [+stress]

In addition, and simultaneously in our model, a bounded clustering operation marks alternate light syllables as stressed.

(35)

Cluster type	syllable
Trigger	# or [-heavy-syllable]
Element	same as trigger
Direction	R-to-L
Domain	bounded
Change	[+stress]

To illustrate, consider the following schematic example. Notice that by assuming that the boundary functions as a trigger we can automatically account for the fact that the alternating pattern stresses odd-numbered syllables at the end of a word but even-numbered syllables preceding heavy syllables.

(36)

	#	CV	CVC	CV	CV	CV	CVC	CV	CV	CVC	CV	#
mora	+	+	++	+	+	+	++	+	+	++	+	
syllable	+	+	+	+	+	+	+	+	+	+	+	
heavy syllable			+				+			+		
trigger element	+			+		+			+			+

When the effects of these two rules are superimposed we end up with [+stress] on the following syllables, represented here with asterisks for convenience:

(37) * * * * * *
CV CVC CV CV CV CVC CV CV CVC CV

An additional, context sensitive, segmental operation is required to account for the main stress falling on one of the last two syllables. Main stress falls on the penult if it is heavy, otherwise on the final syllable of the word. Disjunctive, conditional rules of this sort are awkward to implement in a connectionist network, so an alternative, positive, formulation of the rule must be sought. The generalization is that stress falls on the syllable containing the mora immediately to the right of the mora which is identified with the penultimate syllable bit. The formulation of the rule is slightly complex, but it is an accurate characterization of the process, consistent with all the constraints of the theory and requiring no disjunctive statements.

(38) M [syllable]: [] [] #
 |
 [mora]: [] []
 |
P: [+stress]

The association line between the syllable and mora tiers is intended to represent a segment with both bits activated, i. e. the nucleus of the penultimate syllable. The mora to the right of that segment may actually belong to either syllable. Stressing it predicts stress will fall on the penultimate syllable if it is heavy; otherwise stress will fall on the final syllable.

Thus, main stress falls on one of the last two syllables as a consequence of the interaction of two stress assignment rules both targeting the same syllable. The analysis is fairly simple in that no rule is weird in any way in its own right, it is just the superimposition of all of them that leads to a very complicated stress pattern. Nothing even remotely similar to Halle and Vergnaud's metathesis rule is needed. In fact, all three stress rules can apply simultaneously since they are all independent of one another. This is a significant step towards having a cognitively plausible account of these processes in Aklan. While the analysis is 'derivational' in terms of capturing generalizations through rules, it does not involve the sequential operations necessary in standard metrical theory.

Conclusions

In the proposed theory, there are four basic classes of rules covering the full range of phonological processes; including typical segmental rules, harmony processes and stress. The notions of spreading in autosegmental phonology and headed constituents in metrical theory are both reducible to the clustering operation. Using Aklan as a case study, we have shown that the resulting analyses are not only simpler but also are not necessarily dependent on sequential application of rules. An added benefit is that there is no reason to posit additional theoretical notions like tier conflation or introduce special readjustment rules. The very complicated surface stress patterns in languages like Aklan can be seen to result from the superimposition of a number of fairly simple, independently needed rules.

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